(1)

TECHNICAL REPORT TR92001

NIGHT VISION GOGGLE SIMULATION

OCTOBER 1991

Richard C. Hebb

NAVAL TRAINING SYSTEMS CENTER
ADVANCED SIMULATION CONCEPTS DIVISION
ORLANDO, FL 32826-3224

Approved for public release;
distribution is unlimited.

PAUL LITTLE, Head
Advanced Simulation Concepts
Division

JIM BISHOP, Director
Research and Engineering
Department

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION: UNCLASSIFIED

1b. RESTRICTIVE MARKINGS:

2a. SECURITY CLASSIFICATION AUTHORITY:

2b. DECLASSIFICATION / DOWNGRADING SCHEDULE:

3. DISTRIBUTION / AVAILABILITY OF REPORT: APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED

4. PERFORMING ORGANIZATION REPORT NUMBER(S): NAVTRASYSCEN TECHNICAL REPORT TR-92-001

5. MONITORING ORGANIZATION REPORT NUMBER(S):

6a. NAME OF PERFORMING ORGANIZATION: NAVTRASYSCEN

6b. OFFICE SYMBOL *(If applicable)*: CODE 253

7a. NAME OF MONITORING ORGANIZATION:

6c. ADDRESS *(City, State, and ZIP Code)*: 12350 RESEARCH PARKWAY, ORLANDO, FL 32826-3224

7b. ADDRESS *(City, State, and ZIP Code)*:

8a. NAME OF FUNDING / SPONSORING ORGANIZATION: OFFICE OF NAVAL TECHNOLOGY

8b. OFFICE SYMBOL *(If applicable)*:

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER:

8c. ADDRESS *(City, State, and ZIP Code)*:

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO	WORK UNIT ACCESSION NO.
0602936N	RV36I28		

11. TITLE *(Include Security Classification)*: (U) NIGHT VISION GOGGLE SIMULATION

12. PERSONAL AUTHOR(S): RICHARD C. HEBB

13a. TYPE OF REPORT: FINAL

13b. TIME COVERED: FROM 1988 TO 1990

14. DATE OF REPORT *(Year, Month, Day)*: 1991 OCTOBER

15. PAGE COUNT: 22

16. SUPPLEMENTARY NOTATION:

17. COSATI CODES

FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS *(Continue on reverse if necessary and identify by block number)*: NIGHT VISION GOGGLES, HEAD TRACKING, COMPUTER IMAGE GENERATOR, HELMET MOUNTED DISPLAYS

19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

The use of Night Vision Goggles (NVGs) has increased dramatically and so has the number of accidents attributed to NVG aided flight. The work performed under this project represents an investigation of the use of Night Vision Goggles and the exploration of a method for providing simulation of night vision imagery in an interactive flight simulator environment. The characteristics of the Aviators Night Vision (ANVIS) Goggles were investigated and are summarized. A helmet mounted display concept was developed and a testbed was developed. A commercially available magnetic tracking device was obtained to provide head tracking, and, through a in-house designed interface, was interfaced to a SEL flight computer and various image generators. A Z-transform based predictive algorithm for compensating for the throughput delay image effects of a head tracker, flight computer, and image generator was developed and also integrated into the testbed for evaluation. The helmet display NVG concept represents a good alternative to full up flight simulators of the Weapons Tactics Trainers (WTT) type, and could provide significant enhancements to classroom and on-the-job training. A part task trainer could be developed using the helmet mounted NVG concept that would bridge the gap between classroom and flight.

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT: ☐ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION:

22a. NAME OF RESPONSIBLE INDIVIDUAL:

22b. TELEPHONE *(Include Area Code)*:

22c. OFFICE SYMBOL:

DD FORM 1473, 84 MAR

83 APR edition may be used until exhausted
All other editions are obsolete

SECURITY CLASSIFICATION OF THIS PAGE

*U.S. Government Printing Office: 1986-607-047

THIS PAGE INTENTIONALLY LEFT BLANK.

EXECUTIVE SUMMARY

PROBLEM

The use of Night Vision Goggles (NVGs) has increased dramatically and so has the number of accidents attributed to NVG aided flight. NVGs provide for performance of night missions that were previously either impossible or highly dangerous. NVG use has primarily been in helicopters, and training has been both classroom and on-the-job. The arrival of fixed wing night attack programs involving high speed, low altitude flight and the use of NVGs requires an increase in training, with pilots being subjected to the task loading of simulated flight while using NVGs. Investigations into NVG training methods are a necessary step into providing a means to increase the safe use of the Night Vision Goggle and at a lower cost than current methods of modifying costly Weapons Tactics Trainers.

OBJECTIVES

The work performed under this project represents an investigation of the use of Night Vision Goggles and the exploration of a method for providing simulation of night vision imagery in an interactive flight simulator environment. Tasking included investigating the NVG hardware, learning about current methods of training (both classroom and simulated), and investigating alternate methods of providing interactive flight simulation.

FINDINGS

The characteristics of the Aviators Night Vision (ANVIS) Goggles were investigated and are summarized. A helmet mounted display concept was developed and a testbed was developed. A helmet display from Kaiser was obtained on loan through a Cooperative Research and Development Agreement and integrated into the testbed. A commercially available magnetic tracking device was obtained to provide head tracking, and, through a in-house designed interface, was interfaced to a SEL flight computer and various image generators. A Z-transform based predictive algorithm for compensating for the throughput delay image effects of the head tracker, flight computer, and image generator was developed and also integrated into the testbed. The helmet display concept was integrated with a Paragon Image Generator and McDonnell Glass Cockpit, and also with a Silicon Graphics Image Generator and In-house cockpit.

CONCLUSIONS

The helmet display NVG concept represents a good alternative to full up flight simulators of the Weapons Tactics Trainers (WTT) type, and could lead to a significant improvement over classroom and on-the-job training. A part task trainer could be developed using the helmet mounted NVG concept that would bridge the gap between classroom and flight. Efforts at compensating for the image effects caused by throughput delay using only the predictive algorithm developed resulted in a decrease in image swimming, but did not reduce the effects to an acceptable level. Acceptable compensation requires some level of direct image shifting to remove the residual throughput delay effects.

RECOMMENDATIONS

Further work is needed in developing this concept, including image generator database work, simulated NVG goggle displays, improved head tracker sampling rates, and improved head motion compensation. Several SBIRs are in progress to provide simulated NVG goggles, design and deliver improved head trackers, and design an image generator specifically for providing imagery consistent with NVG characteristics. Also, procurement efforts are underway to obtain a head motion compensation system that is hardware based. This compensation system will use a method that allows the head tracker data to be used in a predictive/corrective manner to control a frame buffer that holds an image generator's output image. The control of the reading out of the image from the frame buffer will allow the image on the helmet display to be shifted to account for throughput delays. These components should be tested in a simulator testbed to establish design guidelines for a fully acceptable NVG simulation

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

THIS PAGE INTENTIONALLY LEFT BLANK.

INTRODUCTION

An increased number of tactical air missions are being carried out under the cover of darkness in response to improvement in small arms and ground to air weapons causing concerns of aircraft losses during daylight hours. Because of increased night mission activity, the use of night vision equipment has increased dramatically to allow pilots to 'see' better during night missions. Figure 1 shows the ANVIS night vision goggle that is widely used by military pilots. Classroom training of pilots for night vision devices is available, such as that provided by the Night Imaging and Threat Evaluation (NITE) lab at Marine Aviation Weapons and Tactics Squadron One (MAWTS-1) in Yuma AZ. Still, accidents using night vision goggles (NVG) have suggested the need for additional training using night vision devices. Emphasis should be placed on maintaining aircraft control while using the NVG to view the night time terrain environment. Simulation training of night time terrain navigation using the NVG goggles would improve combat readiness and safety during night time operations.

The training requirement has come about due to a lack of understanding concerning night illumination of the terrain environment and an inadequate grasp of night vision device capabilities and limitations. Another source of the requirement is an inadequate experience level with night vision devices in the Fleet. The arrival of fixed wing night attack programs using NVG and FLIR require that effective night vision training be implemented.

OBJECTIVE

The objective was to design, develop and demonstrate a NVG simulation. This NVG simulation would be designed to train personnel in the capabilities and limitations of NVG. The NVG simulator could be used for training both helicopter and fixed wing scenarios such as those involving AN/PVS-5, and AN/PVS-6. The simulation should have the capability to demonstrate NVG visual field and imagery limitations, show illumination effects of moon phases and moon angles, show terrain types in varying illumination levels, and show the effects of optical jamming and lasers on NVGs.

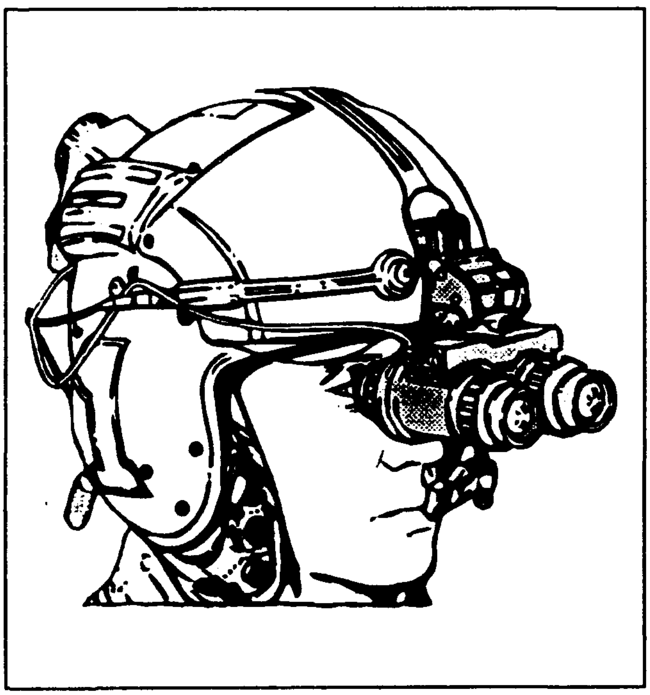

Figure 1. AN/AVS-6 NIGHT VISION GOGGLE

APPROACH

There are several possible approaches to simulation of NVGs. When possible the NVG should be developed from "off the

shelf" components to keep development costs to a minimum. This project's approach to NVG simulation is to develop a pair of training goggles that emulate the NVGs and which could be integrated with a flight helmet. The visual components in this system could be either liquid crystals or miniature CRTs providing a virtual image to the trainee similar to that seen in NVGs. The imagery for the system could be obtained from a polygon or photo based Computer Image Generator (CIG) using an infrared database, or from video recorded night vision goggle imagery if the user is only functioning as an observer. If the user is operating a vehicle simulator, the CIG image source would be needed along with a helmet tracker to tell the CIG the goggle pointing direction as the head moves.

RESEARCH EFFORTS

NIGHT VISION GOGGLES

The initial effort of this task was to investigate the operational NVGs to determine what optical specifications and requirements will be necessary in the simulated goggles. The requirements determined were resolution, field of view, eye relief, spectral range, and image brightness. Also determined was that the goggles provide, in effect, a biocular display. Table I provides a list of relevant NVG characteristics. Note that there are two independent image intensifiers, one per eye, and that there is no angular magnification of the image. Another

AN/AVS-6 CHARACTERISTICS

Field of view	- 40 degrees circular FOV per monocular
Image Magnification	- 1 to 1
Objective Focus	- 10 inches to Infinity
Eyepiece Adjustment	- +2 to -6 Diopters
Wavelength Range	- 550 to 950 nanometers (near-IR)
Image Intensifier	- Generation III Microchannel Plate
Display Phosphor	- P-20 Phosphor, 560 nm. (Yellow-Green)
Net Display Gain	- 25,000-30,000 to 1
Visual Acuity	- 20/40 under Artificial Conditions ~2 Arcmin 20/80 under Ambient Illumination ~4 Arcmin
Display Luminance	- 0.7 to 2.2 FootLamberts
Net NVG Weight	- 16 ounces
Total Helmet Weight	- 5.9 pounds

Table I. NVG CHARACTERISTICS

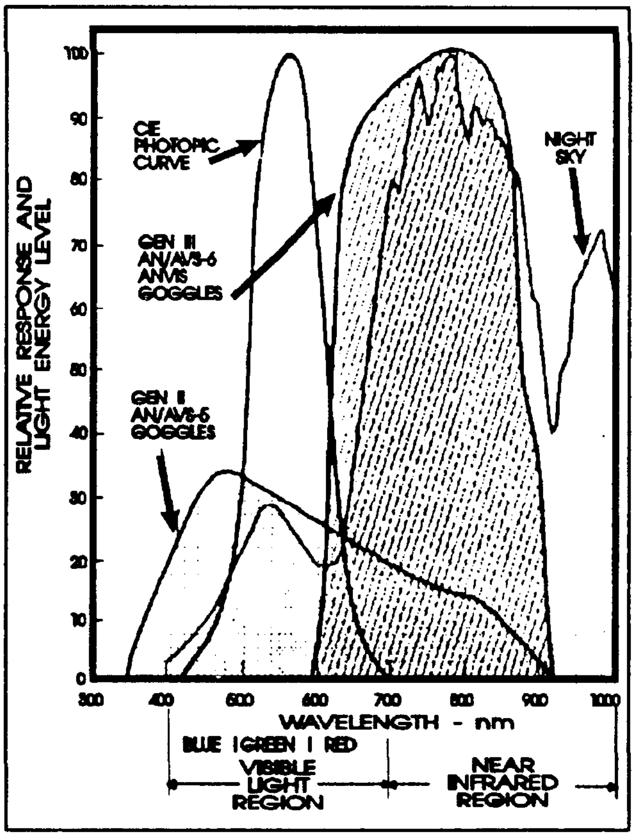

Figure 2. NIGHT VISION GOGGLE RESPONSE

important item to note is that values listed under Visual Acuity are for ideal laboratory conditions only. Under actual conditions of use the visual acuity obtained with the goggle imagery will typically degrade by a factor of at least two.

Figure 2 shows the relative wavelength response of the ANVIS goggles. The CIE PHOTOPIC CURVE is the response of the eye during daytime illumination levels to wavelengths between approximately 400 to 700 nanometers. The NIGHT SKY CURVE reveals the amounts of radiation available mainly due to starlight and moonlight. The GEN II CURVE shows the lower response of the earlier image intensifier which falls over the wavelength range of 350-900 nanometers. The GEN III CURVE, which is used in the AN/AVS-6 or ANVIS goggles, shows a superior response level over a wavelength range of 550-950 nanometers. Note that the response sensitivity has shifted, coinciding with the radiation available from the night sky and away from the wavelengths of most man-made light sources. Despite this shift, the GEN III response falls within the range of the red aircraft cockpit lighting, requiring a filter coating to be applied to the ANVIS objective lenses to reject wavelengths below 625 nm. and reduce the blooming effects of the cockpit lights on the goggle display. This GEN III response is important in the modelling of images for the simulation of NVG scenes, and must be included in the creation process of a NVG image database. Other night database characteristics to be included are the effects of moon illumination (moon position, shadowing, phase of moon), object reflectivity in the near-IR, NVG display blooming effects due to light sources entering the FOV, and weather effects (snow, rain, fog, etc.).

THIS PAGE INTENTIONALLY LEFT BLANK.

HELMET DISPLAY TESTBED

Figure 3 depicts the system concept testbed for NVG simulation. The system design is intended for use in both high performance fixed wing or rotary wing mission simulations. The testbed cockpit was developed to evaluate the use of various helmet mounted display systems in a NVG simulation. From figure 3, this testbed includes a cockpit with flight controls, a helmet display device, a computer for simulating aircraft flight dynamics, a polygon based CIG for imagery, and a magnetic head tracking system that provided head pointing information to the CIG. Almost all the equipment was available in-house equipment, except for the head tracking device and various hardware interfaces.

In FY89, the testbed layout was formulated, the head tracking components were obtained, hardware and software design efforts were initiated to interface the head tracking system into the testbed. This testbed would allow the investigation of the components of a NVG simulation system. Strengths and weaknesses could be defined and improvements or compensation techniques devised to achieve acceptable performance. For example, algorithms were investigated for the compensation of head tracker / CIG throughput delay effects on the projected image during head motions.

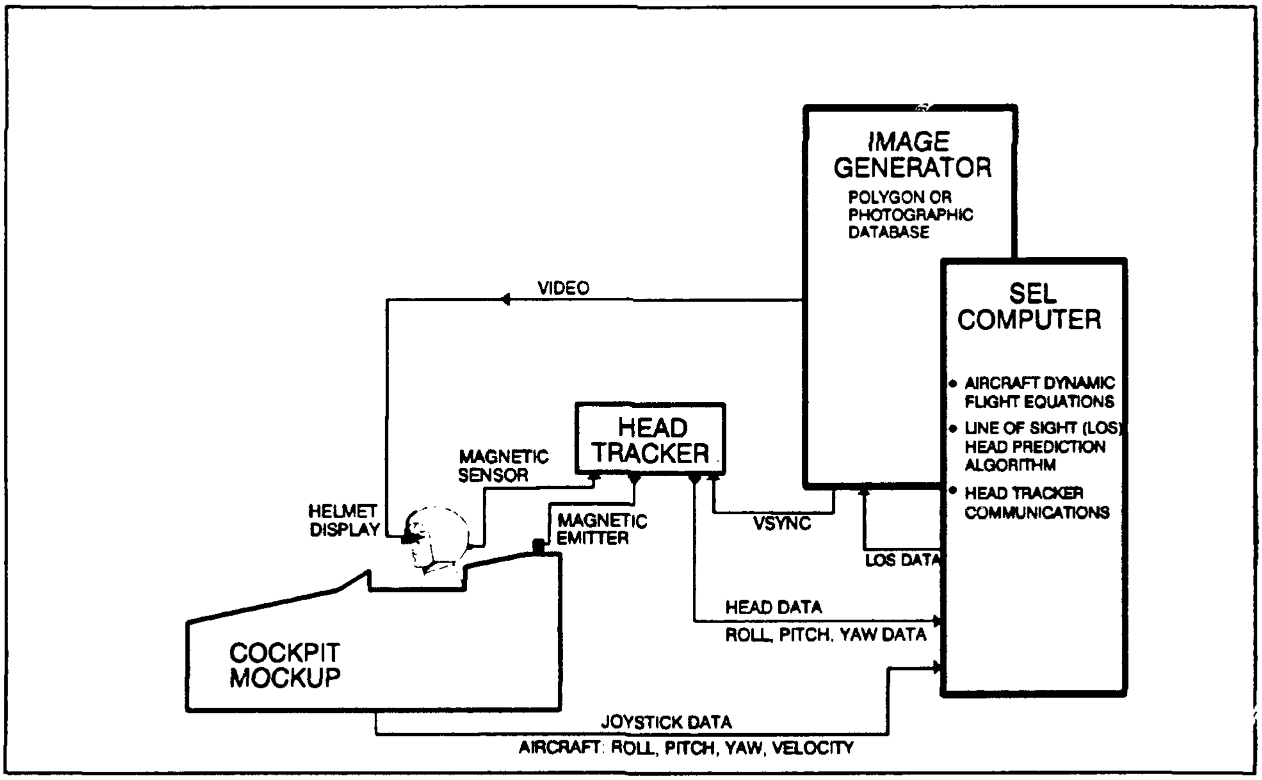

Figure 3. HELMET DISPLAY TESTBED

In FY90, the testbed was completed. A hardware interface was designed and built to allow the SEL computer to take in head tracker (roll, pitch, yaw) data. A head motion

compensation algorithm was designed to investigate reductions in image stability problems initially associated only with image generator throughput delay time. From experiments with the head tracker and displays, the head tracker was found to contribute a considerable delay of about three video field times (approximately 50 msec.). A faster, low cost head tracker system, while not currently available, is seen as a requirement for system improvement. The display systems investigated were the Honeywell IHADDS, Kaiser Wide Eye, and Reflection Technology Private Eye. Other simulated NVG displays are being development under the Small Business Innovative Research (SBIR) program, but have not been available for testing.

The head tracker used was a Kaiser/Polhemus 3SPACE tracker system. The system has a magnetic emitter, magnetic sensor, and a processing unit. The magnetic emitter is mounted to the cockpit structure to provide a reference position and orientation. The sensor, mounted to the back of the users' helmet, allows the tracking of the head orientation angles relative to the cockpit. The tracker system can run at a maximum rate of 60 Hertz, providing head orientation data (roll, pitch, yaw) sixty times per second. The system can be synchronized externally or can free-run. Our interface was designed to use the video vertical sync signal to control the timing of the head orientation data. This synchronization method provides for one set of head orientation data per video field. The angular resolution specification for the 3SPACE tracker is 0.1 degree for orientation, with a static accuracy of 0.5 degree RMS. While the tracker has the capability to track position, we did not use this feature.

Three head mounted display systems were tested. Initially we used a Honeywell Integrated Helmet And Display Sighting System (IHADSS) to experiment with in the NVG testbed. The IHADSS system provided a 525 line or 875 line image with a 40 degrees horizontal by 30 degrees vertical Field Of View (FOV), but only to one eye. Testing of Reflection Technology's Private Eye was limited to the lab. The Private Eye FOV of about 22 degrees horizontal by 17 degrees vertical for only one eye was seen as too small for our experimentation purposes. The Private Eye's lack of video grey scale capability greatly reduces the usefulness of this display for video imagery. The Kaiser Wide Eye helmet display provided a composite FOV of 60 degrees horizontal by 40 degrees vertical when viewed with both eyes. Each eye views a 40 degree circular FOV display with a 50% partial overlap of the two display images. The Wide Eye display uses an 875 TV line monochrome CRT for each eye. Though we did not use it, the Wide Eye provides for stroke writing during vertical retrace. The stroke capability may be useful for writing HUD symbology to be viewed in a simulation.

HEAD MOTION COMPENSATION

Compensation of image stability effects caused by head motions and throughput delays was an area of special interest in this project. For user acceptance the viewed image must be stable, so a software head motion compensation algorithm was developed.

Figure 4 shows the effects that head motion has on a CIG image viewed through a helmet display. At some time T_0 the viewer's head is stationary and is viewing the solid outline house. The solid rectangle represents the outline of the display raster. The viewer starts a move to the right, the display raster and its image contents moves with the viewer because the image

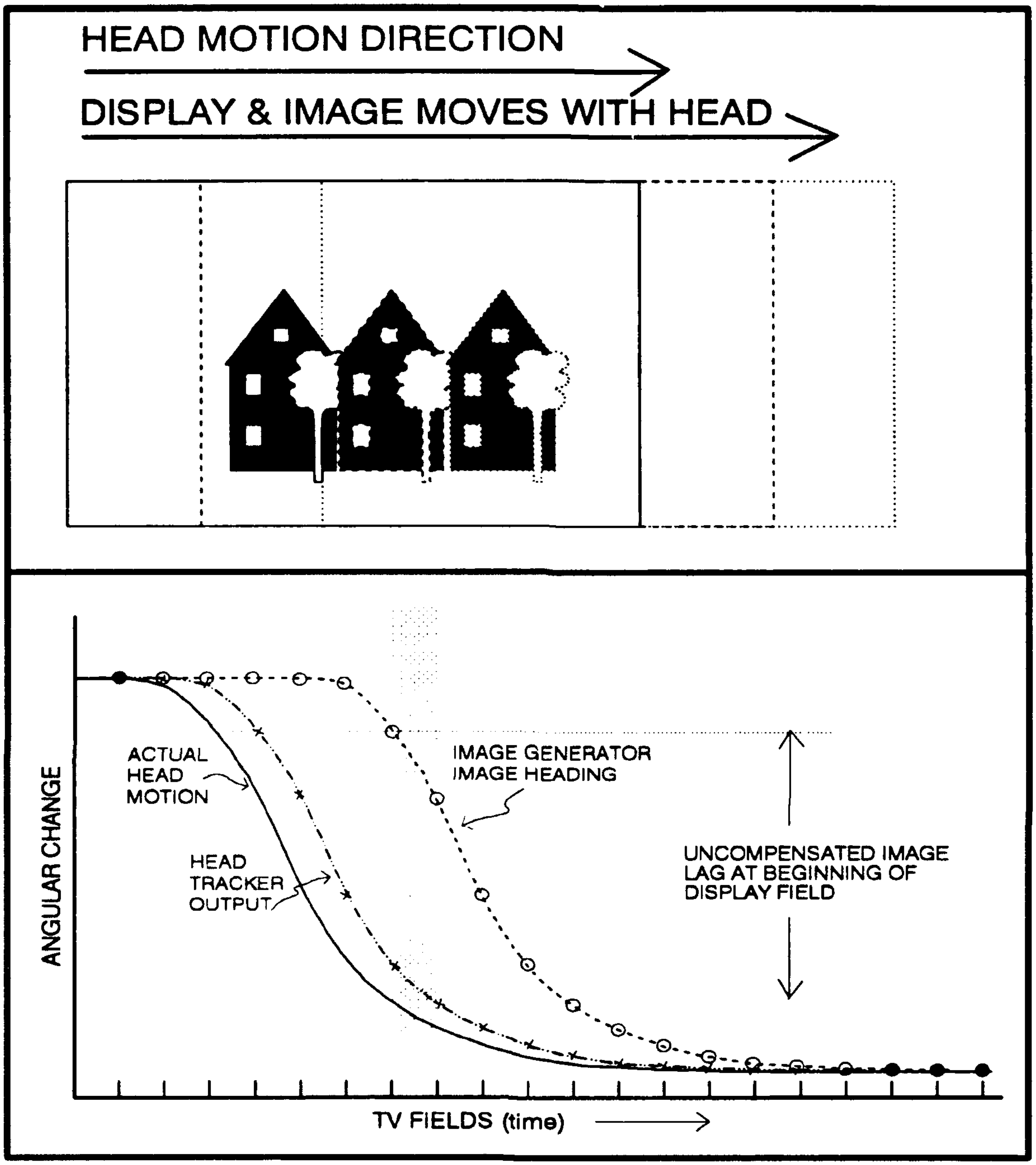

Figure 4. HEAD MOTION EFFECTS

generator is putting out images based on old head angle data. At a time T_1 the viewer sees the house at a new position relative to the background (ie. the cockpit reference) as indicated by the dashed line outlines. As head motion continues to the right, the image continues to follow to the position of the dotted line outlines. At a point in time when the viewer stops his head motion and the image generator catches up to his viewing direction, the image content jumps back to the left into its proper position. The time period here is on the order of 100 milliseconds and is the sum of the head tracker, CIG computation and interface time periods.

The curves in the bottom half of figure 4 show the head motion effect in a different manner. Three curves are shown: solid - actual head motion (also display pointing direction); dot-dashed - output from the head tracker (delayed in time by the head tracker sampling and processing times); dashed - image generator image heading output (showing the heading that the image was calculated for). At the beginning the head is stationary and the three curves are coincident. As a head motion is started, the curves separate with the head tracker output lagging the head by one data period. The image generator output, however, continues to output images according to information received several data periods earlier. Jumping to the end of the head motion, the three curves rejoin.

Taking a look at the shaded data region within the head motion time period, you can get an idea of the image errors that occur. The head motion curve shows the head position versus time (in TV fields) and the head tracker curve shows the concurrent head tracker output (which is behind by some small angle). The image generator curve shows the image heading for this point in time, which is behind by a much larger angle error. The vertical difference between the head motion curve and the image generator curve is the uncompensated image lag, and represents an angular error in image placement. This image placement error, related to the time delay, is the head motion effect that we sought to correct for via a predictive algorithm. The horizontal difference between these two curves represents the time delay. Counting up the time periods between the two curves reveals, in this example, a four field delay.

The method of correcting the head motion effects that we developed and tested was head motion prediction. The prediction relies on the modelling of the head motion as a sine wave. The predictive algorithm developed is a second order phase lead filter, that is the output is a function of the head system's position, velocity and acceleration. Computer simulations were done with sine wave inputs of up to 1 Hz. From these simulations we arrived at initial coefficient values to try to fit the ideal filter curve. Once we observed the desired magnitudes and phase shift characteristics in the output, the filter was then z-transformed to adapt it into the discrete sampling periods of the head tracker and image generator. We then coded the filter to take the head data input, manipulate it, and output angles with the desired phase lead.

The path from head motion input, through the head tracker, head predictor and image generator, to the output of the image is shown in figure 5. Starting with a head motion (depicted as a solid-line sine-wave), the time delay, ΔT_1, of the head tracker causes a phase lag of the original sine wave. The result is the dashed line head tracker sine-wave that is shifted to the right in time. The goal of the predictor is to apply a phase lead to its input to account for not only the head tracker delay, ΔT_1, but also for the upcoming delay associated with the image generator, ΔT_2 . Then the output of the predictor is the dashed line which is shown to the left of the reference head motion sine-wave. This is a shift that represents a phase lead equal in magnitude the phase lag to be caused by the image generator. The end result, after the image generator, is that the image heading coming out of the image generator coincides with the viewer's heading and the imagery is properly positioned.

Referring to figure 5, the ideal predictor for head motion prediction must hold to two relationships: the output magnitude must equal the input magnitude; and the predictor output leads the input by $\Delta T_1 + \Delta T_2$. The phase angle lead, $\Delta\phi$, is equal to the head frequency, Ω,

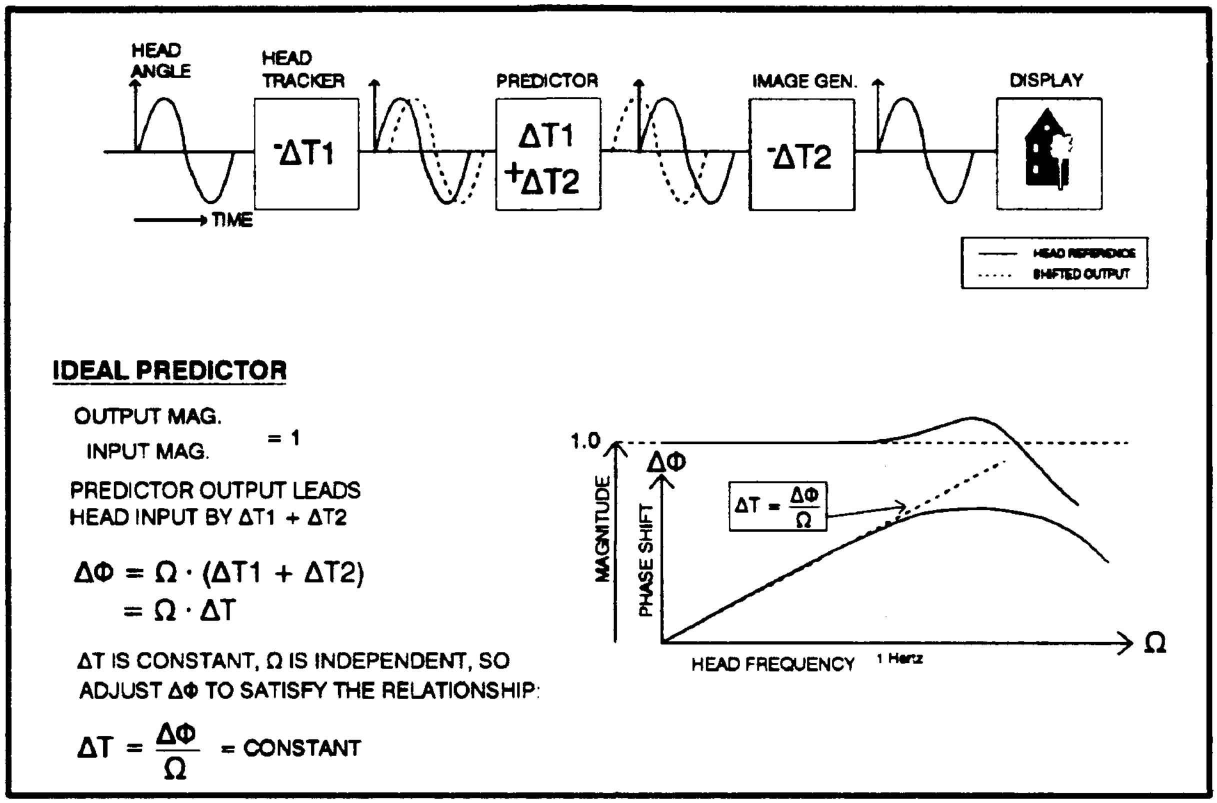

Figure 5. HEAD MOTION PREDICTION

times the total time delay, ΔT. Since ΔT is a constant associated with the head tracker and image generator throughput delay, and Ω is an independent variable (the viewer's random head motion), the only variable we can adjust is the phase angle, $\Delta\phi$, in our attempts to have the predictor output properly lead the input.

The predictive algorithm worked well for constant head motions of varying frequencies. The problem with the predictive algorithm is that there is considerable phase lag at the start of a head motion, roughly 500 to 600 milliseconds. The result is good stability if a user is constantly moving his head, but poor stability if the user randomly starts and stops head motion. Experiments with the filter algorithm led to some refinements of the coefficients, and steady state oscillations were corrected to a satisfactory level. However, head motion transients were still a problem with this filter. Basically, transients cannot be predicted. The graph in figure 5 of HEAD FREQUENCY vs. PHASE SHIFT (and MAGNITUDE) shows the ideal filter relationships as the dashed lines, while the filter performance is shown by the solid lines. Under the sampling rate restrictions and total delay time (greater than 120 msec.) encountered, the filter would not provide sufficient lead when head motions exceeded a 1 Hertz rate.

THIS PAGE INTENTIONALLY LEFT BLANK.

CONCLUSION

The helmet display NVG concept represents a lower cost alternative to using the actual NVG in full up flight simulators and could lead to a significant enhancements to classroom and on-the-job training. A part task trainer could be developed using the helmet mounted NVG concept that would bridge the gap between classroom and flight. It will provide the capability to familiarize trainees with limitations and capabilities of NVG. A fully developed system can demonstrate variations in illumination conditions and terrain interaction required while operating tactical vehicles/aircraft when wearing NVG. The NVG testbed will provide a useful tool for exploring the task of real-time NVG simulation and will assist in future procurements of simulators requiring NVG simulation.

A demonstration was given of a special testbed configuration in August of 1990. The NVG simulation consisted of imagery provided by a Paragon Graphics image generator and displayed on the Kaiser Wide Eye helmet display. This was interfaced with a flight simulator using the McDonnell Aircraft F/A-18 "glass" cockpit. Over 150 visitors viewed the system over a three day period. The demonstration included the use of the head tracked display in several modes to show the differences in compensation software methods for stabilizing the imagery.

Further work is needed in developing the NVG helmet display concept, including image generator database work, simulated NVG goggle displays, improved head tracker sampling rates, and improved head motion compensation. Several SBIRs are in progress to provide simulated NVG goggles, design and deliver improved head trackers, and design an image generator specifically for providing imagery consistent with NVG characteristics. As products from ongoing SBIRs are received, they will be evaluated in the testbed developed. The lessons learned in this effort will be applied to other ongoing projects concerning NVGs and helmet displays.

Efforts at compensating for the image effects caused by throughput delay using only the predictive algorithm developed resulted in a decrease in image swimming, but did not reduce the effects to an acceptable level. Acceptable compensation requires some level of direct image shifting to remove the residual throughput delay effects. Procurement efforts are planned for FY91-92 to obtain a head motion compensation system that is hardware based. This compensation system will use a method that allows the head tracker data to be used in a combination predictive/corrective manner to control a frame buffer that holds an image generator's output image. The predictive method developed during this project will be used to reduce the magnitude of the image placement error, while the reading out of the image from the frame buffer will allow the image on the helmet display to be shifted to account for throughput delays.

THIS PAGE INTENTIONALLY LEFT BLANK.

DISTRIBUTION LIST

Defense Technical Information Center
FDAC
ATTN: J. E. Cundiff
Cameron Station
Alexandria, VA 22304-6145

Commander
Naval Air Systems Command
Naval Air Systems Command Headquarters
Code PMA 205
Washington, DC 20361-0001

Commanding Officer
Naval Training Systems Center
Code 2
Orlando, FL 32826-3224

Commanding Officer
Naval Training Systems Center
Code 25
Orlando, FL 32826-3224

Office of Naval Technology
Code 20T
800 North Quincy Street
Arlington, VA 22217-5000

Office of Naval Technology
Code 222
ATTN: Dr. Stan Collyer
800 North Quincy Street
Arlington, VA 22217-5000